Observational & Modeling Studies In Support Of The Atlantic Stratocumulus Transition Experiment

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LONG-TERM GOALS

Our long-term goal is to learn how to predict the cloudiness, entrainment rate, and turbulent fluxes in the marine boundary layer under any and all large-scale conditions.

OBJECTIVES

Examine the effects of varying sea surface temperature, varying inversion strength, and varying mean winds on cloudiness, entrainment rate and turbulent fluxes in the marine boundary layer; The cloud types to be examined include fog, stratus, stratocumulus, and shallow cumulus clouds, with or without mesoscale organization.

Describe the spatial properties of tropical deep convection by examining its spectral properties in the wavenumber-frequency domain and explore relationships between the spatial distribuiton, amount, and intensity of deep convection and tropical cyclone activity.

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Explore the inference of aerosol microphysical characteristics utilizing passive shortwave radiation measurements.

APPROACH

Our approach is primarily theoretical on the boundary layer flux probem, but we are making use of data from FIRE, ASTEX, and BOMEX to test our theories. We are using numerical models to make connections between the theory and the data. We are also testing our ideas using the results of large eddy simulations (LES) performed by our colleague Dr. Chin-Hoh Moeng, of NCAR.

For the deep convection studies a space-time spectral analysis was performed on daily averaged estimates of ISCCP deep convective cloud amount between January 1, 1986 and December 31, 1988.

The approach for assessing aerosol microphysical inferences included both theoretical modeling of the radiative transfer and analysis of some initial observations.

WORK COMPLETED

Rawinsonde data collected from the Atlantic Stratocumulus Transition Experiment (ASTEX) were used to investigate the mean and temporal characteristics of large-scale heat and moisture budgets for a two week period in June 1992. During this period a large apparent heat sink and apparent moisture source were observed near inversion base. Analyses from other budget studies show that similar convective signatures occur in a wide variety of regimes when trade-wind type inversions are present. In the lowest kilometer the vertical eddy flux of moist static energy over the ASTEX domain (centered at 33N with an average sea-surface temperature of 19.4 C) is about 60% of that observed in the undisturbed trade-wind regime of BOMEX (centered at 15N with an average sea-surface temperature of 28.1 C).

The apparent heat source, apparent moisture sink and convective flux of moist static energy over ASTEX were strongly modulated on a synoptic time scale by the passage of fronts and by fluctuations in the subsidence rate associated with changes in the strength and position of the subtropical high. The influence of midlatitude disturbances on convection over ASTEX further distinguishes this region from typical trade-wind and tropical regimes. Daily budgets were examined for three different convective regimes during ASTEX to determine the mechanisms contributing to the large synoptic variability over this region. Details of these results are presented in Ciesielski et al. (1999).

RESULTS

This past year we have extended the budget analyses presented in Ciesielski et al. 1999, to study diurnal variability over the ASTEX region. The diurnal cycle was examined for several fields, including surface fluxes of sensible and latent heat (as deduced from buoy measurements), fractional low-cloudiness (using METEOSAT satellite analyses), and vertical cloud boundaries (using ceilometer, radiometer, cloud radar and sound observations). In addition, daily variations of several fields are investigated using time-height diagrams. These fields include various parameters which enter into the heat and moisture budgets (temperature, water vapor mixing ratio, vertical motion), the budgets themselves, radiative heating, and the vertical eddy flux of moist static energy.

Preliminary results show a diurnal range in the subsidence rate over ASTEX that varies between 1.9 and 2.7 mb/hr. On a diurnal time scale, the peak subsidence occurs at 2200 LST and has maximum amplitude above and within a few hundred meters of the inversion level. This suggests that cloud radiative effects play a role in determing the characteristics of the diurnal cycle over this region. Comparison of the diurnal cycle of vertical motion over ASTEX to adjacent regions, suggests that the hadley circulation over the North Atlantic is pulsing on a diurnal time scale. Mechanisms proposed for this pattern of diurnal pulsing include the role of day/night variations in longwave cooling in clear and cloudy regions, and day/night variations in cloud top radiative effects.

The deep convection study results suggest that while variability in deep convection is primarily red in the space time domains (low frequencies and wave numbers), it is not coupled to any of the equatorial waves predicted by Matsuno (1966). The Madden Julian Oscillation however does appear to significantly modulate the amount of deep convection. There are two possible explanations for the differences between our results and those of WH98. First, our data extends over a shorter time period which makes it more difficult to identify signals in the background noise. Second, equatorial waves which modulate outgoing longwave radiation do not modulate deep convection.

Satellite observations show that there are typically large bursts of deep convection during the early stages of tropical cyclogenesis (Zehr 1992). From a statistical point of view, it therefore seems natural to expect that time periods characterized by greater (lesser) amounts of more (less) intense deep convection will also be characterized by enhanced (suppressed) tropical cyclone activity. Figure 3 allows for comparison of deep-convective cloud amount and deep-convective cloud brightness temperature in the East North Pacific averaged over four active tropical cyclone months (July, August, September, October) to that averaged over four inactive months. Note that differences in 500 mb omega and precipitation rate are also shown. Here deep convective cloud includes all pixels with cloud top pressures • 440 mb and optical depths • 23. As is expected, active months are characterized by larger amounts of colder deep-convective cloud. Qualitatively similar results were found in other regions characterized by tropical cyclogenesis, i.e. the West North Pacific, North Indian Ocean, and Southern Hemisphere. A summary of results for the North Atlantic has been given by Tulich (1999). Montgomery and Enagonio’s 1998 theory for tropical cyclone formation provides a possible physical explanation for our results. In their theory, bursts of deep convection are thought to occur at random on the periphery of an incipient meso-scale vortex. These bursts generate local positive potential vorticity anomalies in the lower troposphere which propagate radially inward and spin-up the parent vortex. This “statistical” theory for tropical cyclogenesis naturally implies that there will be greater probability for tropical cyclone formation during months when there are a greater number of deep convective bursts.

Using numerical simulations of radiative transfer through an aerosol medium for two different fields of view (0.75 and 2.0 degrees), we have shown that the peak in the transmittance ratio for the two fov’s occurs at approximately the same value of the effective size parameter for a variety of microphysical distributions. This suggests a means of estimating the effective particle size from surface observations of transmitted solar radiation through aerosol layers, including clouds. Details are available in Cox and Davis (1999).

IMPACT/APPLICATIONS

The ASTEX budget analyses when combined with previous and future budget studies from other global regions will help us elucidate the role that stratocumulus cloud regimes play in our global climate system. Also, diurnal studies such as that conducted for the ASTEX region offer the opportunity to further our understanding of convective phenomena and how they are controlled by, and interact with, large-scale circulations.

Because tropical cyclones devastate property and take life, it is important to understand the physical mechanisms which control their frequency of occurrence.

Remotely inferred microphysical properties of aerosol layers could be parlayed into accurate estimates of line of sight attenuation throughout the electromagnetic spectrum and hence a prediction of “smart” weapons performance. The advantage of a passive system is that it gives no signature to an antagonist whereas an active system would.

TRANSITIONS

General circulation modelers will make use of the observed convective flux profiles presented in Ciesielski et al. (1999) to improve and refine their cumulus parameterization schemes in subtropical regions.

RELATED PROJECTS

We are investigating the development of new, more accurate bugdet methods based on a very exact formulation of moist thermodynamics. With the advent of GPS sondes and the recent availability of certain satellite data products, this more accurate treatment of moist thermodynamics should provides us with opportunities to refine our understanding of subtropical and tropical cloud regimes.

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